A Java-Applet-Based Three-Phase Power System Harmonics Simulator

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Abstract - **This paper presents the development of a Java applet to simulate three-phase power system when harmonics is being introduced. The applet-based makes the simulator a very useful visual tool in understanding how harmonics affects the shape of sinusoidal waveform and thus the quality of power resulted thereof. The use of Java applet also enables the simulator to be run through internet via web-browser, and hence improves its availability and accessibility. The skeleton of the simulator will first be described. Then, discussion on how to operate the simulator follows which includes an example with snapshots to demonstrate the execution of the simulator.**

I. INTRODUCTION

The problem of power system harmonics is not new. Utilities recognized the consequences of harmonics in the 1920s and early 1930s when distorted voltage and current waveforms were observed on transmission lines. At that time, the major concerns were the effects of harmonics on electric machines, telephone interference and power capacitor failures. Although such concerns still exist today, harmonics are becoming a serious problem, potentially damaging consumer loads as well as power delivery equipment because of the ever-growing popularity of power electronic device that causes substantial increase of harmonic-producing loads in recent years.

Significant efforts have been made in the past two decades to improve the management of harmonics in power systems. Standards for harmonic control have been established. Sophisticated instruments for harmonic measurements are readily available. The area of power system harmonic analysis has also experienced significant developments. Well-accepted component models, simulation methods and analysis procedures for conducting harmonic studies have been entrenched. Harmonic studies are becoming an important component of power system analysis and design. The effects of harmonics in power systems are gaining increasing interest associated with increasing applications of power electronics devices. It is useful, therefore, to develop a simulator that will facilitate investigations of the effects that harmonics have on electrical systems. One such simulator has been established at Cal Poly State University using the Lab-View platform. However, Lab-View package is very expensive, and one needs to be familiar with the platform in order to run the harmonic simulator. Another disadvantage is that one will have to come to a computer in which the Lab-view program is resided in order to use the harmonic simulator. Therefore, the availability and accessibility of the harmonic simulator are limited due mainly to the significant cost of acquiring the Lab-view program. The next logical step is, therefore, to implement a different approach to improve both the availability and accessibility of the harmonic simulator.

The strategy is to realize a different platform that will run the simulator and at the same time avoiding the obstacles associated with the Lab-view platform. A web-based harmonic simulator such as using Java-applet is one solution that perfectly suits the needs. By using a web-based environment, the convenience of running the harmonic simulator can be provided since one may run the simulator from any computer with internet access and web-browsing capability. In order to run the web-based harmonic simulator, one needs not be familiar with the platform underlying the simulator, since the web-based environment will eliminate direct involvement between the user and the platform. In other words, the web-based presentation will provide the ease of point and click operation. Furthermore, to gain access to the harmonic simulator, one needs only to acquire a web-browser with Java capability. The web-browser is presently available for free, and can be easily downloaded and then installed in a computer. Therefore, the requirement of purchasing expensive software such as in the case of the Lab-view version of the simulator can be eliminated. Last but certainly not least, the use of a web-based environment possesses one crucial advantage, that is the harmonic simulator can be accessed and therefore run by more than one person at a time from any place in the world. Thus, the web-based version will greatly improve both the availability and the accessibility of the harmonic simulator.

II. POWER SYSTEM HARMONICS

A good assumption for most utilities is that the sine wave voltage generated in bulk power station is very good. In most areas, the voltage found on transmission systems typically has much less than 1.0 percent distortion [1]. However, as we move closer to the load, the distortion increases, At some loads, the current waveforms will barely resemble a sine wave. One that is mainly responsible for causing this is the presence of power electronic converters that chop the current into seemingly arbitrary waveforms. While there are a few cases where the distortion is random, most distortion is periodic, or harmonic. That is, it is nearly the same cycle after cycle. This has given rise to the widespread use of the term harmonics to describe perturbations in the waveform [1].

For a three-phase balanced system under non-sinusoidal conditions, the n^{th} order of harmonic voltage of each phase can be expressed as [2]:

$$v_{an}(t) = v_{a0} + \sum_{n=1}^{N} \sqrt{2} v_n \sin(n\omega t + \theta_n) \qquad (1)$$

$$v_{bn}(t) = v_{b0} + \sum_{n=1}^{N} \sqrt{2} v_n \sin(n\omega t - 2n\pi/3 + \theta_n) \qquad (2)$$

$$v_{cn}(t) = v_{b0} + \sum_{n=1}^{N} \sqrt{2} v_n \sin(n\omega t + 2n\pi/3 + \theta_n) \qquad (3)$$

Where $v_{a,b,c\text{-}0}$ are the dc-offsets of each phase. Moreover, each phase may consist of positive, negative and zero sequences, and therefore they need to be taken into consideration when computing for the overall harmonic effect.

The harmonic simulator is constructed by first breaking the three-phase system into the corresponding positive, negative, and zero sequence. Under each sequence, harmonics and dc-offset are then being introduced in each phase a, b, c except for the zero sequence in which the harmonic for the three phases is governed by a same equation. Once all the harmonics have been defined for each phase and sequence, then the main window can be accessed to display the aggregate effect in the three-phase system.

III. TOTAL HARMONIC DISTORTION

Total Harmonic Distortion or THD for short is commonly used to measure the harmonic content of a waveform. It is calculated as follows (for either voltage or current):

$$THD = \frac{\sqrt{\sum_{n=2}^{N} M_n^2}}{M_1} \qquad (4)$$

where M_n is the rms value of harmonic component n of the quantity M, and M_1 is the fundamental component. THD is therefore a measure of the effective value of the harmonic components of a distorted waveform relative to the fundamental. The Java-applet based harmonic simulator computes this THD once any harmonic is added into a waveform in each phase.

IV. EXAMPLE

The following discusses an example that will demonstrate the Java-applet based harmonic simulator.

Default Display - Positive Sequence

When first loaded, the simulator will be defaulted to show the positive sequence - phase A at which point the plot window should show a clean sine wave. The user may then add harmonics into phase A, phase B, phase C by selecting the phase and then click the add button. A small pop-up window will then appear. In this window, the user may specify the harmonic number to be added and its corresponding magnitude in peak and phase angle in degrees. Figure 1 through Figure 3 depict this process.

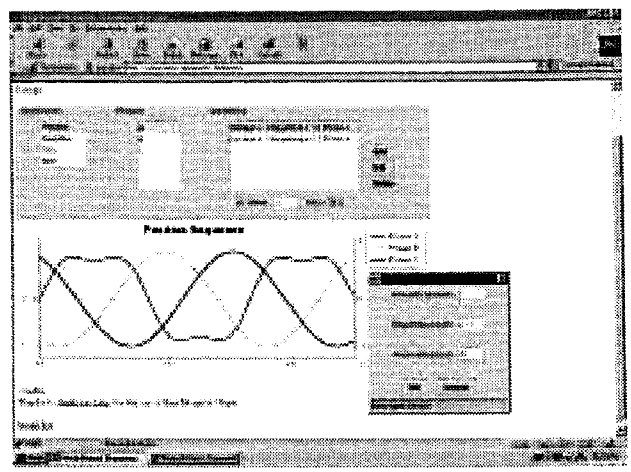

Fig. 1. Harmonics are being added to Phase A - Positive Sequence

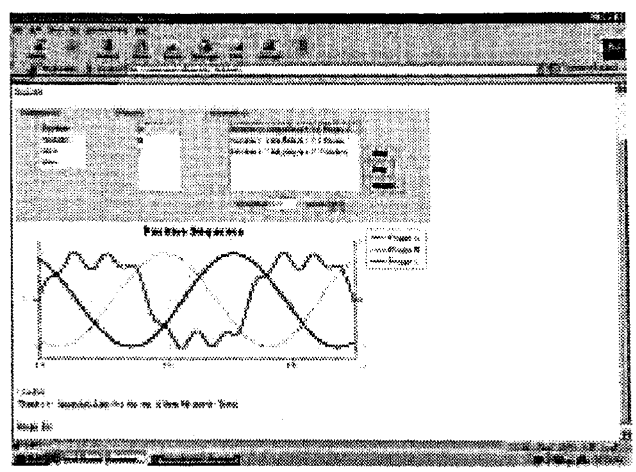

Fig. 2. Distorted waveform of Phase A - Positive Sequence

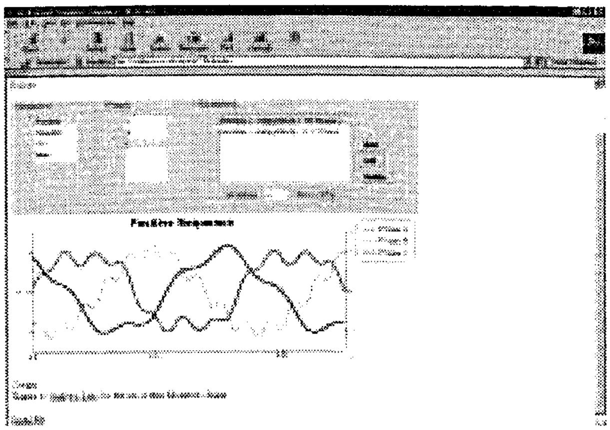

Fig. 3. Distorted waveforms in positive sequence

Negative Sequence

Here the same process as was done in the positive sequence can be performed again for phase A, B, and C. Notice that dc-offset can be added also besides the harmonics themselves. Figure 4 illustrates the effect of inserting the dc-offset in addition to the harmonics, while Figure 5 shows the complete distorted waveforms in the negative sequence.

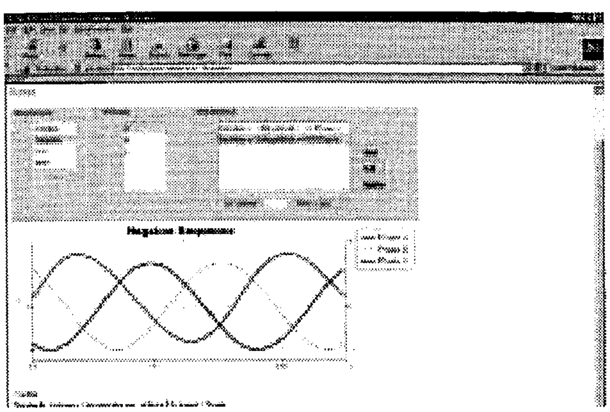

Fig. 4. Added dc-offset in phase A - negative sequence

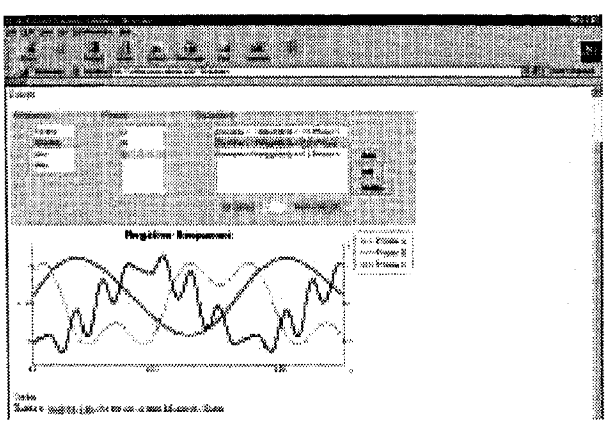

Fig. 5. Overall distorted waveforms - negative sequence

Zero sequence

In this sequence, all three phases have the same equation and so only one of the phases needs to be displayed (Figure 6). Harmonics are added in the same way as was done previously in the positive and negative sequence.

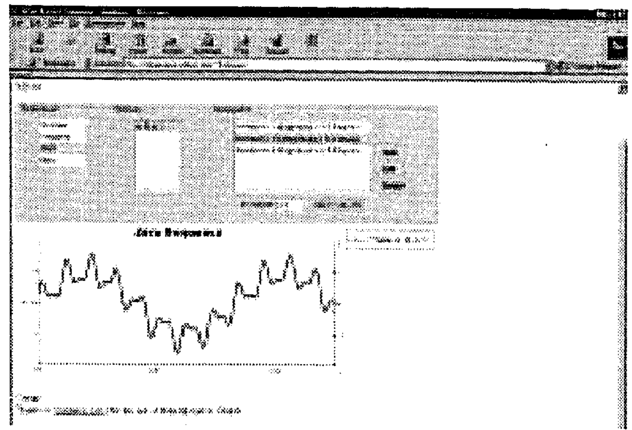

Fig. 6. Distorted waveform in zero sequence

Main Display

Here, the corresponding harmonics in the positive, negative and zero sequences are aggregated into their corresponding phase A, B and C main waveforms. The resulting main waveforms for this example is shown in Figure 7.

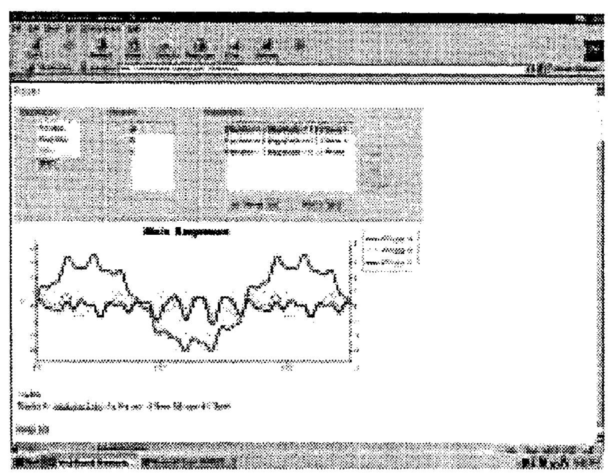

Fig. 7. Main waveforms of Phase A, B, and C

Once the simulation is completed, the user may conduct another set of simulation simply by clicking the reload command located on the top portion of the page.

Where to find the Simulator

The final version of the web-based or Java-applet harmonic simulator will reside in the electrical engineering department webserver at Cal Poly State University in San Luis Obispo. The URL is: http://www.ee.calpoly.edu/harmonics
Currently, the simulator can be run through a web-browser with Java Plug-in version 1.1.2. capability. The authors will appreciate any comments and suggestions to improve the presentation of the simulator.

V. CONCLUSIONS

In this paper, the Java-applet based three-phase power system harmonic simulator were presented. The simulator may serve as a powerful visual learning aid to learning the harmonics. Java-applet approach was chosen since web-based environment for the simulator will be readily applicable. Hence, the simulator possesses flexible accessibility and availability for its users. Further work for this project is still undergoing to enhance the presentation and speed of the simulator through more efficient programming algorithm. Moreover, the simulator will also be extended to incorporate hardware interfacing to the existing voltage harmonic simulator at Cal Poly State University, San Luis Obispo.

REFERENCES

[1] R.C. Dugan, M.F. McGranaghan, H.W. Beaty, *Electrical Power Systems Quality*, 1st ed., McGraw-Hill, New York, 1996.

[2] G.W.K. Chang, *Harmonics Theory*, Tutorial on Harmonics Modeling and Simulation, IEEE Press, 1998.

BIOGRAPHY

Dr. Taufik received his B.S. degree in Electrical Engineering and minor in Computer Science from Northern Arizona University in 1993. He continued his education and received his M.S. degree in Electrical Engineering and Computer Science from the University of Illinois at Chicago in 1995. He then received his Doctor of Engineering degree from Cleveland State University in May 1999 with specialization in Power Electronics. His research interests include power converter topologies, resonant converters, web-based educational tool, computer modeling and simulations, and FACTS devices.

Linda Kakinami is currently a student at Cal Poly State University in San Luis Obispo and will be finishing her degree in Computer Science in Fall 2001. Her interest includes web programming and software engineering.